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Monterey, California

ORGANIZATIONAL DECISION MAKING

William C. Giauque

August 1975

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ORGANIZATIONAL DECISION MAKING

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FOREWARD

Traditionally top management decision making relies heavily on informal techniques -- intuitive judgments by experienced managers, traditions and "rules of thumb" peculiar to each organization, or informal consensus among a group of managers. This report surveys the potential role of and desirability of more formal approaches to some top management decision problems.

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Decision Making in Large Organizations

It is tempting to point out the lack of formal techniques typically used by large organizations, digress on the advantages of formal over informal methods of decision making, then conclude with a list of specific decision areas in which formal techniques should be instituted. Before going into this, however, it is worth noting that formal techniques, whether they go under the guise of computerized management information systems, operations research, decision theory, or what have you, have a disappointing track record in general management, although there have been, to be sure, some outstanding successes. Part of the reason for this may lie in the way decisions tend to get made in organizations, whether the methods used be formal or informal. This subject is discussed in Section A. Then in Section B. a taxonomy of decision making is developed and discussed, with particular emphasis on matching problems with potential solution techniques. Section C. describes the elements of one particular analytic approach, decision analysis. Finally in Section D. the problem of using analytic methods, including decision theory, in an effective manner in real organizations is taken up. This section includes a review of the literature dealing with applications of decision theory in large organizations, and summarizes some general principles of insuring successful applied work.

A. Organization Goal Setting and Decision Making

In traditional economic theory, business firms act in such a way as to maximize profits, given that there are behavioral constraints imposed by the competition, the marketplace, government, and society. The picture of decision making in this theory is that of managers and

A.1. Organizational Goals

Any organization is, at heart, a coalition of individuals, each with his own set of goals. These individuals are, in turn, organized into groups, the groups into larger groups, and so on, with each level adding a new set of goals. How then does one manage to set goals for the entire organization without causing fatal conflict? There are two answers to this question: first, the goals themselves are structured in such a way as to avoid conflict; and second, the goal setting mechanism allows for conflict resolution.

Goals are rarely structured in precise, unambiguous terms. On the contrary, studies of organizational objectives suggest that agreement on objectives usually exists only when objectives are highly ambiguous, and that behind this agreement lies considerable uncertainty and disagreement on subgoals. To a large extent critical areas of conflict are never brought into the open, and agreeing, in essence, to disagree is usually a semi-permanent way of life. Goals which are set usually take the form of aspiration levels, which are subject to change over time, rather than imperetives to "maximize" or "minimize." This tends to make conflict resolution less urgent, as organizational units are judged by the degree to which they attain the aspiration levels, which are largely set according to past experience, rather than by what is theoretically possible.

The goal setting mechanism is also an important stabilizing influence. Organizational goals are not, as a rule, set through a process of analytic determination of optimal procedures, but through a bargaining process. The parties to the goal-setting reach agreements through sharing rewards, not only such monetary rewards as budgets,

salaries, and contracts, but nonmonitary rewards as well: promotions, citations, policies, personal treatments, private commitments, etc. This process allows parties to settle conflicts through relatively non-disruptive mechanisms. The objectives resulting from this process have a number of important attributes (Cyert and March, op. cit., page 32):

1. They are imperfectly rationalized. The exact forms of the agreements will depend at least as much on the bargaining skills of the leaders, the history of the bargaining session, and the particualr resource scarcities faced as on the merits of the issues themselves.
2. Some objectives are stated in the form of aspiration-level committments, such as "We must allocate ten per cent of our total budget to research." The determination of the "ten per cent" undoubtedly has little to do with cost/benefit analyses of the particular research projects available, but a good deal to do with the presitge, power, and persuasiveness of the research director.
3. Some objectives are stated in a nonoperational form. Such objectives have the advantage of being consistent with virtually any set of operational objectives. For example, nonoperational goals are evidenced in such political rhetoric as "We must 'crack down' on crime, while simultaneously protecting citizens rights and eliminating police brutality." This can be cited in favor of such diverse operational goals as increasing the use of wiretapping and eliminating the use of wiretapping.

Once organizational objectives have been established, a number of stabilizing mechanisms tend to make them permanent. Budgets are based partly on past budgets. Allocations of functions and other precedents are rememberd

and followed, sometimes taking the form of "rules of thumb" or "the usual way we do things," and occasionally becoming part of the standard operating procedure. Thus accidents of organizational geneology tend to become perpetuated, to be abandoned only under pressure. Furthur, organizations tend to build up a certain amount of "fat" (termed "organizational slack" by Cyert and March). In case of adversity, this provides a cushion so that business as usual can continue, perhaps indefinitely or at least until a new bargaining cycle can be completed.

It is worth contrasting the preceeding description of organizational goal setting with an objective, or "rational" procedure, which would require the firm to predict the environment, survey all possible actions, then pick a set of goals which would result in the best actions. It is not at all clear that the objective procedure, even if it were possible to implement it, would be the better way to choose goals. Clearly the actual process contains valuable mechanisms for keeping the organization stable and viable, and substituting the "rational" procedure could easily result in the surfacing of chaotic conflict.

A.2. Organizational Expectations

Expectations are seen as the result of drawing inferences from available information. Thus, while goal setting might be seen as both a way of stating what considerations are important in an organization and of setting up evaluation standards, expectations might be thought of as projections of what will happen. One can study expectations, then, both from the standpoint of how inferences are drawn and of how information is made available in the organization.

On the subject of inference drawing, two general observations can be made. First, expectations are biased, both consciously and unconsciously, by hopes, wishes, goals, and internal bargaining. The manipulation is usually subtle, but is occasionally overt. A classic case of the latter occured in a major Naval weapons system acquisition procurement project, which suffered a budget cut severely limiting the number of units to be purchased for the fleet. The cut was justified by a study showing that the new lower number of weapons (less than half the number originally planned) was adequate to meet the needs of the fleet; however, the study was in response to, rather than in anticipation of, the budget cut. Secondly, it appears that the computational power and precision available in organizations is limited. One observes that only on a few of the potentially relevant variables is data gathered and projections made. Also, the projections that are made tend to be very simplistic, requiring a minimum of calculation. There is, of course, nothing wrong with simplicity, but by and large the capacity for more sophisticated methods seems to be lacking, even when such methods may be justified.

Information availability within an organization is strongly affected by the nature of the data gathering system. Information becomes available in a fragmented, sporadic fashion at different organizational and geographic locations. Communication of the information is subject to severe bias, delay, and filtering effects; internal communications is, in fact, a significant competitive weapon within the organization. Thus the communication system introduces significant distortion into the system; over the long run, however, systematic bias seems to be at least partially detected and accounted for.

Most significant decisions require information which is not readily available, thus implying the need for a search

prodedure. In rational economic theory, a firm would have a portfolio of potential investments, against which new proposals would be continually evaluated. Information search should, in theory, be treated just like any other proposal, as a potential investment of resources which is expected to yield a benefit. An information search project, if accepted, would be analagous to a prospecting expedition; the world is searched in a systematic way with particular data needs in mind, and any nuggets of information found are brought back and assayed. In reality, this ideal picture is inaccurate on a number of counts. First, project evaluation and information search don't occur continually, but only as a result of fairly obvious problems. Organizations don't plan nearly as much as they fight fires, reacting to current crises. Second, search activity is not itself treated as an investment. Rather, there are various levels of search activity that are called into play, so that for a given situation there is a standard search procedure. Further, the criterion of search activity is feasibility rather than optimality. As soon as something is found that seems to (more or less) solve the problem, the search stops; the only questions asked are "Is it feasible?" and "Is it better than what we have now?", rather than "Is this the best possible way of handling the problem?". Finally, the search procedure is not nearly so much a prospecting expedition as a mating dance. The direction of the search is largely determined by the conspicuousness of the alternatives, and as various people, both inside and outside the organization, have their own interests tied up in the decision they naturally try to make their preferred alternatives the most conspicuous ones. Thus, the organization is not only in search of information, but interest groups are trying to make at least parts of the information known to the organization.

A.3. Organizational Choice

Now that we have discussed how a firm identifies what it is concerned with (organizational goals) and how it foretells results (organizational expectations), it is possible to discuss how the choices are actually made. Briefly stated, there are three basic principles in decision making: 1) avoid consideration of uncertainty; 2) maintain organizational rules and precidents; and 3) keep decision rules simple.

It seems paradoxical to speak of firms avoiding the consideration of uncertainty. After all, the world is uncertain whether one likes it or not. There are procedures, however, which minimize the need to predict uncertain events. First, as summarized above, firms do very little meaningful long range planning, moving instead from one crisis to the next. Second, firms rely heavily upon standard rules for doing things, whether these be traditional methods, general industry practice, or standard operating procedures. These not only influence (and in many cases dictate) the decisions which are made, but provide stability and predictability to the organization. Thus, when Department A is working on a problem, it is already known what the responses of Departments B and C to their parts of the same problem are going to be. In addition, planning records made within the organization act to fix committments and expectations. "Plans, like other standard operating procedures, reduce a complex world to a somewhat simpler one. Within rather large limits, the organization substitutes the plan for the world -- partly be making the world conform to the plan, partly by pretending it does." (Cyert and March, op. cit., p. 112). When possible, organizations arrange a negotiated environment.

The stabilizing influence of standard procedures would

largely be lost if the procedures were to change frequently. The procedures build up around themselves a myriad of precedents, understandings, and unspoken connotations, thus becoming entrenched. When procedures are changed there is always a period of uncertainty and unsettlement until things "get worked out" again. The second principle of decision making, then, is to maintain the organizational procedures and precedents.

The third and final principle is to keep decision rules simple. Generally one searches for feasible alternatives (rather than optimal ones) and implements the first one encountered. Thus the search procedures strongly affect the decision making process. There are, of course, problems which come up which are not adequately covered by standard procedures. Rather than elaborate procedures to cover a wider variety of problems, organizations opt to keep the rule simple and rely on individual judgement to provide flexibility.

A.4. Summary

The impression given by the discussion above is that of organizational decision making which is in a narrow sense irrational, but in a broader sense very rational. The fact that such behavior is nearly universally observed strongly indicates that it is functional, even vital, to the operation of the firm.

What then is the value of discussing analytic techniques for making decisions?

First, it is important to recognize the potential of analytic techniques. On problems that are reasonably complex, particualrly when uncertainty is involved, formal

techniques can, if used properly (and that is a big "if"), nearly always result in better decisions. Second, effective use of formal techniques does not require replacement of the entire corporate decision making apparatus. An individual manager can make effective use of such techniques on problems falling within his own area, or in broader problems, to yield results for his own evaluation of alternatives, or as ammunition in corporate give and take. The techniques themselves are useful for broad or narrow problems, or for top or lower level decisions; however, due to the fact that at some levels, for some problems, explicit rationality would be a positive hinderence rather than a help, one should pick the problems to be analyzed rather carefully. This issue is discussed furthur in Section D., after the techniques themselves are classified and discussed in the next two sections.

B. Decision Making - A Taxonomy

There are any number of ways of classifying decisions - by subject area (inventory decisions, personnel decisions, etc.), by managerial level (top level decisions, middle level decisions, lower level decisons), by importance (critical, major, minor, etc.), and so on. A taxonomy should, though, be an aid to good decision making, not simply an arbitrary classification scheme. Ideally a decision maker could use a taxonomy not only to attach a classification label to a given decision problem, but to find an approach useful in solving his problem. Thus, the starting point in constructing a decision taxonomy is to consider the decision making process itself. This is done in Section B.1. Then in Section B.2. the taxonomy is presented and discussed.

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B.1. The Decision Making Process

Decision making involves, in essence, four steps, forecasting or projecting, identifying alternatives, determining measures of effectiveness of possible outcomes, then making the choice. The first step, forecasting or projecting the needs of the organization, the outside envioronment, future constraints upon the organization, and so forth, defines the context against which any decision must be evaluated. In some decisions this step is critical; determination of capacity needs in training facilities depends on forecasts of training volume and methodology, for example. There are other cases where this step is less important, as in choosing among methods to present a standard block of training. In forecasting, it seems useful to distinguish two extreme situations. The first extreme, called in this paper a "well defined" situation, is one where the objectives, the constraints, the structure, and the relationships among variables in the problem are relatively well understood. A good example of this is an inventory policy decision. Demand is well understood and, though uncertain, amenable to analysis. Costs of carrying a given inventory level can be defined and calculated. Costs of a stockout, though harder to calculate, can still be understood and approximated. Relationships among supply, demand, stock level, lead times, etc. can be easily specified. Contrast this with the other extreme, an "ill defined" situation, such as a decision problem like "what should CNET's policy toward enlisted personnel training be over the next five years?" Here a good deal of effort must be expended simply in defining the critical questions, the alternatives, and relevant considerations before the problem can be meaningfully discussed. Initially, at least, the ill defined problem would seem to call for a different type of approach than the well defined problem.

Another characteristic of decision problems which can be observed during the forecasting phase is the importance of uncertainty. Occasionally the uncertainty in a problem is relatively minor, so one can act as if all relevant factors were known. Many resource allocation problems and scheduling problems, for example, are of this type. Most real problems, however, involve uncertainty to a major degree, and decisions made under the assumption of certainty may be grossly misleading. Thus, one must adopt different techniques for dealing with these two types of problems.

The second step in decision making involves specifying alternatives. In well defined problems these are usually readily apparent; in the inventory policy decision, alternatives are defined by all possible stock levels and reordering policies, and the choice of the inventory control mechanism itself. In ill defined problems a major effort may be needed to define a set of reasonable alternatives. If uncertainty is a consideration, then it may be necessary to specify contingent, as well as immediate alternatives. Thus, techniques for dealing with decision problems under uncertainty must include methods of identifying and describing contingent decision structures.

In the third step in the decision process, measures of effectiveness are specified. This involves considering the job to be done and identifying considerations relevant in evaluating alternatives. Sometimes a single measure can be identified as an overriding consideration, but more often one must deal with multiple criteria, some of which may not be measurable. Suppose, for example, that the job is to train pilots. Some relevant considerations are the length and cost of training, final pilot proficiency, capacity of the training pipeline, and a number of others. Only some of these considerations are directly measurable, so it is necessary to specify ways of estimating non-measurable

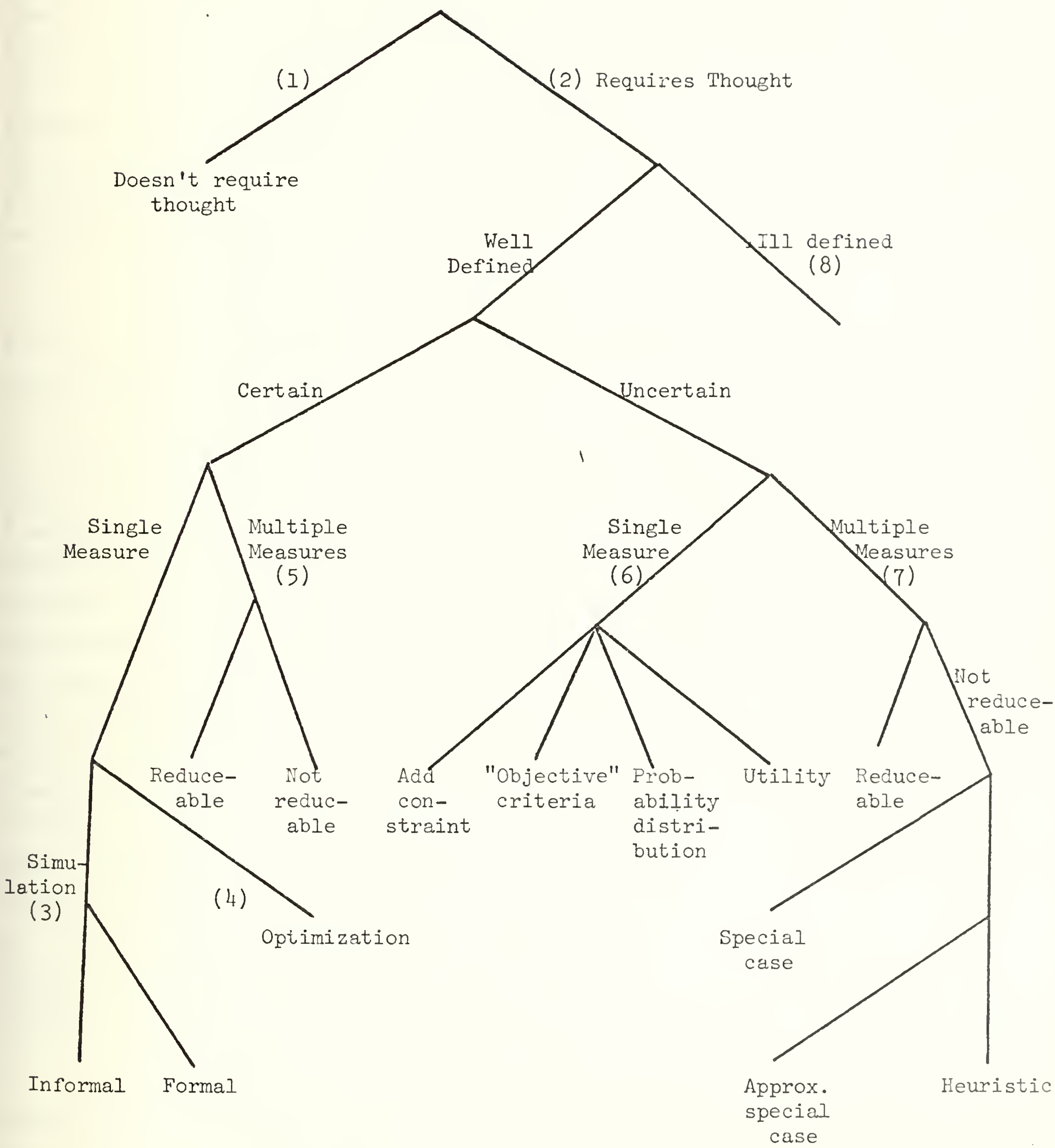
outcomes. An approximate measure of pilot proficiency, for example, can be constructed by use of subjective evaluations, such as instructor comments, and results of quantitative tests, such as proficiency exams. Finally these various measures are combined into a single measure of effectiveness. As a rule this last step is not performed explicitly; it is unusual to find a manager who has specified in any coherent manner the kinds of trade-offs he is willing to make among effectiveness measures. Usually decisions are made on a case-by-case basis by consensus or "common sense"; these intuitive decisions do, however, define implicit trade-off structures.

The final step in decision making is to select the best alternative among those specified. A variety of techniques, ranging from snap judgements to sophisticated and expensive computerized models are available to aid this step. Indeed, a major purpose of this taxonomy is to wed the decision problem with the appropriate technique. The taxonomy and the matching of problems and techniques is considered in the next section.

B.2. The Taxonomy

The taxonomy developed in this research is outlined on Figure 1. Branches on the breakdown tree in Figure 1. are numbered, so that the discussion below can be keyed to the appropriate part of the breakdown structure. Note that the major breakdowns, between well defined and ill defined problems, certain and uncertain problems, and between single and multiple measures of effectiveness, follow suggestions made in the preceeding section of this report. An additional breakdown, between problems not requiring thought (branch [1]) and those requiring thought (branch [2]), is

Figure 1. A Decision Taxonomy



introduced at the top of the breakdown structure. This is introduced, somewhat facetiously, as a reminder that many problems are too trivial, too obvious, or too constrained to justify detailed analysis. Throughout the discussion of this taxonomy, in fact, it is important to remember that the scope and expense of the analysis and the magnitude of the original problem must be kept in proportion. Most of the solution methods discussed below can be applied in either relatively simple or relatively complex manners, depending on the demands of the problem.

B.2.a. Well Defined, Certain, Unidimensional Problems (Branches [3] and [4])

In discussing the taxonomy, consider first a problem which 1) requires thought, 2) is well defined, 3) can be treated as certain, and 4) has a single measure of effectiveness. Most real problems aren't this uncomplicated, but this simplest case is important as an approximation for many real problems and as an introduction to the more complex situations. Nearly all solution techniques for more complex problems consist, in fact, of ways to reduce them to this simplest case, then using the techniques for this case to solve the problem. An enormous variety of techniques suited for such problems is known; here they are classified broadly as simulation techniques (branch[3]) and optimization techniques (branch [4]). Some of these solution techniques require computers for useful implementation. The role of computers in organizational decision making is discussed briefly in Section B.3.

Simulation techniques are, at heart, projection techniques. Given a particular decision, the simulation method predicts the outcome. In order to determine the best decision, then, one must redo the simulation many times,

trying all possible decisions in order to find the best one. Informal, "seat-of-the-pants" judgements are classified as simulation techniques in this report, as judgements consist essentially of projecting the consequences of an action, then choosing among the actions. Simulation techniques can be extremely straightforward. Every manager who has projected a cash flow, forecast expenses, or set up a budget has, in effect performed a simulation. The idea in simulation is to formulate a set of rules which govern the behavior of a system, then apply those rules to see how the system acts. In forecasting expenses, for example, a very simple system rule is "total expenses is equal to the sum of all expense categories." It is then a trivial matter to see how total expenses vary as each expense category is varied. Although this particular simulation model is, in its own way, very useful, it is limited in the insight it can give. It is possible to build much more complex simulations, perhaps to relate expenses to the output of the organization, or to take account of the interdependencies among the various expense categories. The more complex the simulation becomes, the more expensive, time consuming, and error prone it becomes, but the more potential usefulness it has. There have been many cases where complex simulations yield insights impossible to obtain in any other way.

Optimization techniques differ from simulation techniques in that optimization techniques are designed to not only predict outputs, but to determine automatically the best possible decision. The price one pays for this additional feature is usually a good deal of additional complexity. It is difficult to conceive of any "quick and dirty" optimization technique. There are, however, a number of "standard" types of problems (such as linear programming models) which can be relatively easily solved. If a particualr problem fits one of these types, then optimizing may be straightforward, although perhaps expensive. This is

a big subject, and a complete discussion of optimization is well beyond the scope of this report. An introduction to this field can be found in any good book on operations research. A particularly useful one is Principles of Operations Research by Harvey M. Wagner, Prentice-Hall, New Jersey, 1969. A good, elementary, managerial-oriented discussion of optimization and simulation, with examples of how each can be applied, is contained in Chapters 6 and 7 of Advanced Methods and Models by Springer, Herlihy, and Beggs, Richard D. Irwin Inc., Homewood, Illinois, 1965.

B.2.b. Well Defined, Certain, Multidimensional Problems (Branch [5])

Consider now a slightly more complicated decision problem, one that is still well defined and can be treated as certain, but where multiple measures of effectiveness exist (branch [5] on Figure 1). There are two approaches to this situation. First one might try to express all the measures in terms of some common measure, such as dollars. Suppose, for example, one must decide whether or not to install an expensive computer system to individually manage student instruction, and that tests have shown a decrease in the average length of training time under the computerized system. There are multiple measures in this decision, dollar cost and average training time. These could, however, be reduced to a single measure, dollars, if one could express the worth, in dollars, of having a student complete training earlier. There are a number of other techniques, some fairly simplistic and some quite elegant, for reducing multiple criteria to a single criterion. These will be discussed somewhat furthur in Section C.3. in this report. Once a single criterion is established, then either simulation or optimization techniques can be used to solve the problem.

In some problems it is easier to work directly with multiple criteria than to try to reduce them to a single criterion. If the problem is solved by a simulation technique this is no particular problem; outcomes projected by the simulation technique are characterized by many measures of effectiveness rather than one, and in the end the decision maker must choose among them. Thus, although he may be able to avoid an explicit specification of the trade-offs he is willing to make among objectives, he cannot avoid striking some kind of balance among them in the final analysis. If one wishes to use an optimization technique to solve the problem then working with multiple criteria becomes very difficult. It is possible to make some use of optimization; for example one might do a number of optimization calculations, each time using a different measure of effectiveness as the optimized criterion. With some luck this would narrow the choices down enough to effectively solve the problem. In the more general case, though, it is difficult to make good use of optimization.

B.2.c. Well Defined, Uncertain, Unidimensional Problems (Branch [6])

Turning now to the case of a problem in which uncertainty is important, though the problem remains well defined, consider first a problem with a single measure of effectiveness (branch [6]). This has been an extremely important special case, particularly in the financial literature, and has given rise to a number of ideas, all of which are designed to translate this problem to an equivalent problem under certainty, so that the usual simulation and optimization solution techniques can be used. Before discussing these approaches, a bit of terminology must be introduced. In an uncertain problem one does not, by definition, know in advance the exact value of the

outcome for any decision. One always knows, though, that for a given decision some results are more likely than others. It is possible to express this knowledge by describing, or assessing, a probability distribution for the outcome. Given the probability distribution, one can calculate a number of data, the most important of which are the mean or expected value (a measure of the average value of the outcome) and the standard deviation (a measure of the spread, or variability, in the outcome). It is also possible to calculate the chances of any given value of the output being exceeded.

The first approach to solving these problems ignores uncertainty, in effect, as long as it stays within predefined limits. In setting up the problem the decision maker can specify such constraints as his maximum allowable loss, or the probability that costs, for example, exceed a given figure. Within these bounds he uses some simple measure of outcome, usually the expected value, to solve his problem. In this way he translates the uncertain problem into a constrained problem under certainty, which is readily solved by certain optimization techniques.

A second approach doesn't utilize the probability distribution as such but embodies such ideas as "Let's assume that the worst (or best) possible event will occur, then maximize our gain under that assumption." It has been pointed out that this approach can lead to overly pessimistic (or optimistic) decisions, so a variation has been developed which allows the decision maker to express his personal attitudes toward risk by picking a value for a "pessimism factor," which is then used to balance the best and worst cases. Still another variation assumes that all uncertain events are equally likely, then maximizes the expected value of the criterion.

The third approach consists of defining a new, certain easure of effectiveness, most commonly by subtracting a onstant times the standard deviation from the expected alue of the outcome. The rationale is that, variations eing equal, one would choose the alternative with the igher expected value. If variations are not equal, then ne must have a higher expected value to offset the dditional risk of the larger variation. One is allowed to et the degree of offsetting required by picking the value f the constant referred to above.

All these approaches are useful in certain ircumstances, but can be shown to lead to irrational ecisions in other cases. A more general approach, known as tility theory, can be shown to be valid for all problems, iven that one believes some basic assumptions about the eaning of the term "rationality." In the utility approach he decision maker expresses his attitudes toward risk in he form of a curve, called a utility curve. The utility urve is then used along with the probability distribution entioned above to calculate a measure of "goodness" which ccounts automatically for the uncertainty in the results. his utility measure can then be used with any of the echniques discussed under branch [3] to solve the problem. his approach, although unfamiliar to many managers, is traightforward. A more detailed discussion of utility easures is contained in Section C.3.

.2.d. Well Defined, Uncertain, Multidimensional Problems Branch [7])

Consider now a problem which is well defined, but where ncertainty is important and multiple measures of ffectiveness must be considered (branch [7] on Figure 1.). ometimes the criteria can all be expressed in terms of a

common measure, as was discussed for problems with multiple criteria with no uncertainty (branch [5]). To take the same example, it might be possible to approximate the worth, in dollars, of shortening training by one day, then express the uncertainty both in the cost of the computer system and in the number of days by which training would be shortened in terms of a single, uncertain, total dollar figure. The problem could now be solved by methods discussed under branch [6].

In many problems it is impossible to express the criteria in terms of a single criterion. A second approach exploits the ideas of utility theory, discussed briefly above. In the case where a single criterion exists in an uncertain problem, one expresses his attitudes toward risk in the form of a utility curve. In this case, where multiple criteria exist, one can, in theory, do the same thing, except that the utility curve becomes a 3-dimensional or higher dimensional curve, a utility hyperplane. Because of practical difficulties, it is possible to determine what this hyperplane looks like only for certain special cases. Fortunately most real problems can be treated as one of the special cases, so the multidimensional utility approach can be an extremely useful analytical tool. Even if a problem is one which doesn't fit the "special case" category, one can usually get a good approximate solution by treating it as if it were, then seeing how sensitive the results are to the utility assumptions.

A third approach to this class of problems consists of using heuristic approximation techniques, or in more everyday language, using reasonalble ideas that seem more-or-less to work. One might, for example, select what he considers the most important outcome measure, get a rough idea of the probability distribution of that outcome, then make a tentative decision based on that; he would then check

the other outcome measures to make sure that his solution wasn't ridiculous before making the decision final. Another commonly used approach has been to set "aspiration levels" on all the criteria, then to search for a decision alternative which has a reasonable chance of attaining all the aspiration levels. In choosing training methods, for example, one may set limits on the cost and the length of training, the physical facilities needed, and the prerequisites on the student input, then choose the method which seems to have the best chance of meeting the limits. The major problem with such heuristic methods is that they depend heavily on the ingenuity and judgement of the human decision maker, and humans can be shown to be notoriously poor processors of uncertain, multidimensional information. Both the methods mentioned above, plus many others one could conceive of, can lead to bad decisions at times. Somewhat more structured approaches can usefully suppliment, though not supplant, the capacities of human judgment.

B.2.e. Ill Defined Problems (Branch [8])

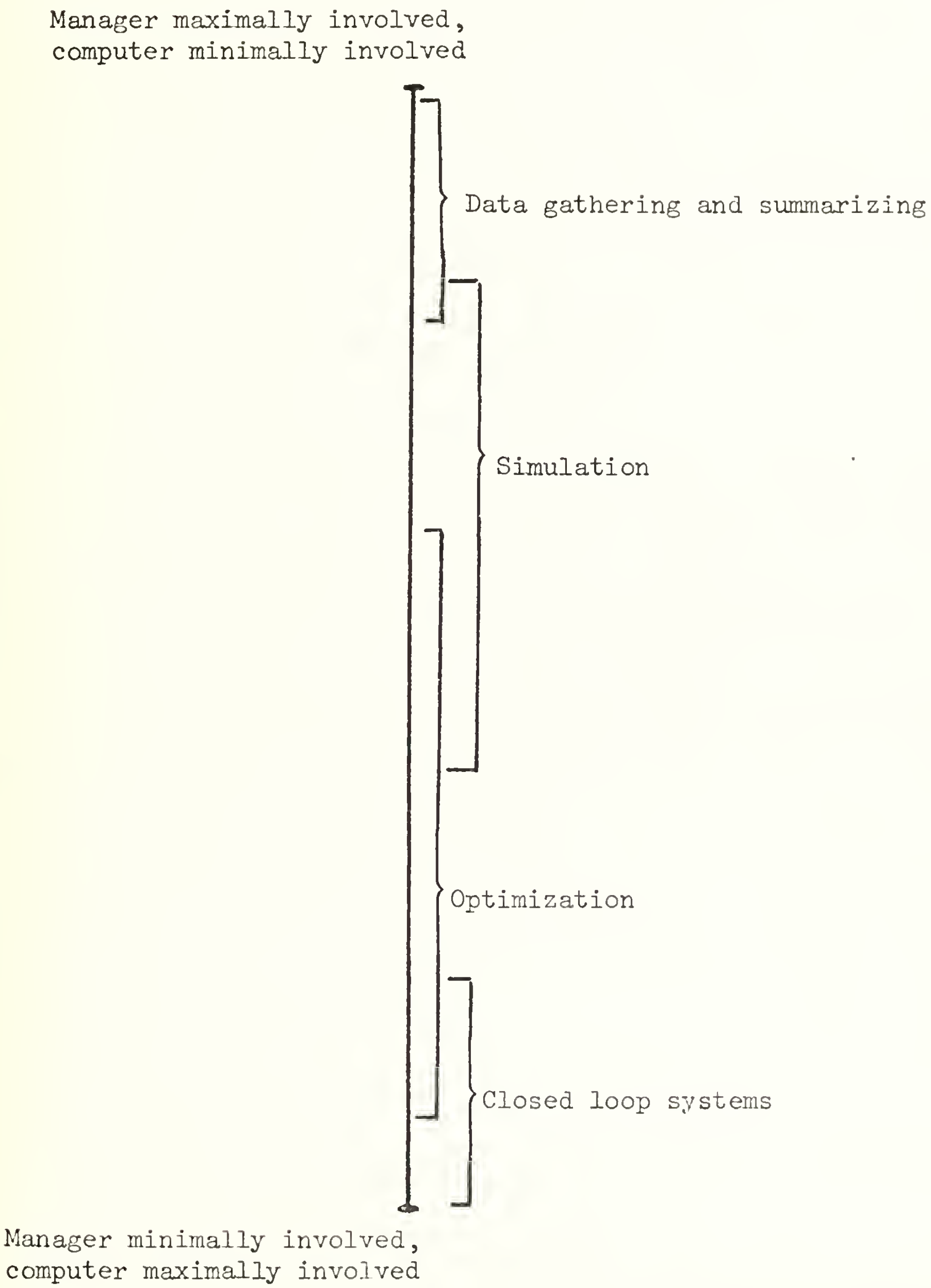
The final category in the taxonomy consists of ill defined problems (branch [8] on Figure 1.), which are defined here as problems in which the alternatives, issues, and consequences are poorly defined and/or understood. Solving an ill defined problem requires first making it into a well defined problem; doing this requires a different type of effort than discussed so far. Any real situation is infinitely complex in detail, so the first step in analysis is to identify the major issues and constraints in a problem. Next, the major action alternatives should be outlined, and some thought given to the impact of each possible action upon the major issues. Third, the most promising alternatives are selected for furthur study, then this process repeated. Thus, the process of analysis is

cyclical rather than linear. With each cycle the problem and the issues become successively better defined until the problem can finally be effectively defined and solved. In the early stages of problem definition formal approaches are of limited use, as the problem is mainly one of encoding impressions, knowledge, and attitudes. Even at this stage, however, systematic methods of thinking can pay dividends. A systematic approach to decision making, both in ill defined and well defined situations, is outlined in the next section. Some of the component parts of this approach, namely unidimensional and multidimensional utility theory, have been referred to above, while other parts have only been alluded to.

B.3. Role of Computer-Based Methods

Before concluding the discussion of organizational decision making, some comments regarding the role of computers is appropriate. Computers, of course, have the capacity of processing enormous amounts of data at staggering speeds with excellent accuracy. In addition, it is possible to build a good deal of sophistication into computer programs. This can, under the proper circumstances, allow a manager to supplement his own expertise with the intelligence which went into designing the computer program. For these and other reasons piles of computer printouts, and occasionally computer time sharing terminals, are becoming increasingly common sights in managers' offices. The precise role played by the computer in the decision making process can, however, vary a good deal. One critical dimension to the computer's role, namely the relative involvement of the computer versus the manager in making decisions can be depicted as shown in Figure 2.

Figure 2. Involvement of Computer vs. Manager in Decision Making



At one extreme, the computer can be used simply as a data gathering and summarizing tool. The manager retains not only all decision making perogatives, but the bulk of the analytical workload. The computer may do a minimal amount of computing (summarizing, calculating ratios, computing variances, etc.), but the primary use of the computer in this mode is to feed data to managers for their analysis and interpretation, and to handle routine paperwork. The bulk of current applications are of this type. Managerial and cost accounting systems, payroll systems, and many production control systems, to name a few examples, can be classified in this category.

The prevalence of such data gathering and file maintenance systems has lead to the creation of sizeable and reasonably complete data bases. These data bases are, in most cases, potentially valuable for a variety of managerial purposes. Data gathered and stored as part of a payroll system, for example, is frequently useful in the analysis of productivity and the projection of employee expenses. Data from a billing and invoicing system can be used in inventory control. The Navy maintains extensive records on equipment maintenance and failure histories as part of the 3-M system; this data is potentially useful to the training command in indicating problem areas and possible training deficiencies. The usefulness of a given data base for a new purpose is limited, however, by the organization and scope of the data. Usefulness of 3-M data to the training command, for example, is limited by the fact that the training record of the man responsible for given equipment is not recorded.

A more complex category of applications involves using the computer to analyze data through simulation models. As explained in Section B.2.a., simulation techniques involve representing a system in a mathematical form. Consider, for

example, a simulation model to predict student throughput in a training program. There are a number of factors which clearly affect throughput, such as the nature of the training to be performed and the skill level desired, instructor availability and skill, the amount and type of training equipment available, student intelligence and motivation, and so on. The builder of the simulation model attempts to determine which of these factors are most important in determining throughput, and just how the critical factors interrelate to determine the throughput. He then puts these relationships into a mathematical form which can be used in a computerized model. Once this is done, the manager can use the simulation model in a number of ways -- to forecast some figure of interest, such as the budget required to produce a given student throughput, to perform "what if" analyses, to plan and design a new system or a change to the present system, or in many other ways. A feature shared by all simulation models is that the human, the manager, remains in the decision loop. The computer simply projects the effects of a set of assumptions, and it is up to the manager to examine the results and either change the assumptions and perform additional analysis, or to make a final decision.

The next level of computer application involves the use of computerized optimization techniques. Optimization techniques, being designed to automatically determine the best possible decisions in a given situation, have the capability of removing the manager from direct involvement in the decision process. Usually, however, the manager is involved in interpreting and implementing the analytical results. Indeed, most optimization techniques are designed to yield information not only about the optimal decision, but information on the sensitivity of the result to various data and assumptions used in the model. The purpose of this is to allow the manager to estimate the impact of factors

not included in the model, and to explore the feasibility of alternatives other than those derived by the optimization technique. Thus, the manager and the computer usually supplement one another in the decision process.

Finally, there are some cases when it has been shown useful to eliminate the manager from the decision process altogether. In many inventory systems a computer not only sets reorder points and quantities, but places the order as well. The only impact the manager has on this process is to occasionally review the system performance and to adjust the rules by which the computer makes its decisions. Production scheduling and process control are other areas where this "closed loop" approach has been applied. All these applications occur in situations which are repetitive, and where the major variables in the decision process are known.

C. Outline of Formal Decision Analysis

The decision aids outlined in the previous section, although useful, don't provide a general method of attacking most managerial decision problems. In these other areas nearly all decisions are made intuitively, and there are some circumstances when some better method than intuition is desired. Perhaps the decision is of major importance, or the complexities and uncertainties of the problem are such that there is a need to integrate the expertise and knowledge of a number of people in the organization, or perhaps there is a need to explain the issues and trade-offs in the problem to someone else, either a superior an ally. In any event, there are circumstances when a rational, systematic method of outlining the decision process is needed. The bag of techniques for doing this are known collectively as "decision analysis" or sometimes "decision theory." Very briefly, use of these techniques allows one

to

1. outline all alternatives and to consider all possible consequences of each alternative in a systematic way,

2. break a large, complex problem down into a series of smaller, simpler problems so that different experts or organizational units can contribute to the solution of the problem in their particular areas,

3. specify and quantify uncertainty, and determine how critical the uncertain variables are,

4. specify, in a logical manner, the trade-offs one is willing to make among outcomes,

5. determine the worth of gathering furthur information, and finally

6. determine which decision is the best one to make, and to calculate a measure of how much better that decision is than any other alternative. This last point is useful in deciding, for example, whether factors ignored in the formal part of the analysis could possible change the decision.

The methods used to accomplish these purposes are summarized below. Basically there are four steps to decision analysis: (1) structuring the problem; (2) determining uncertainty; (3) determining preferences for outcomes; and (4) obtaining results. These areas are discussed in Sections C.1. through C.4. below. Comments on practical methods of applying decision analysis are also made in Section C.4.

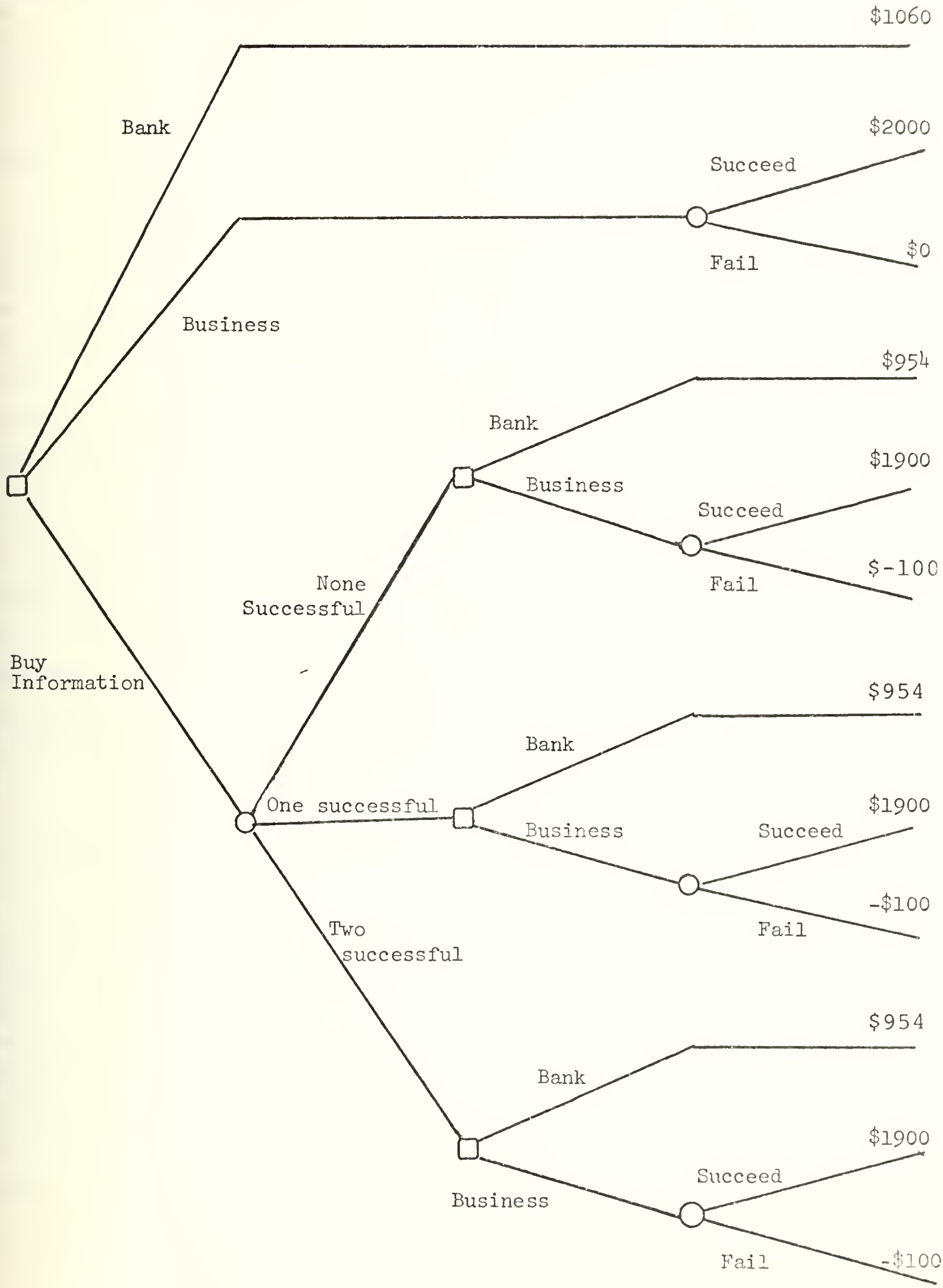
C.1. Structuring the Problem

Consider, for the purpose of illustration, a highly simplified decision problem. Suppose you are trying to decide whether to invest $1000 of your money in a bank, where you are assured a 6% annual return, or in a business venture. If the business is successful you would receive a

100% return over the next year, while if it went broke you would lose everything. You will cash in your investment at the end of one year in any case. To keep the problem simple, assume these are the only two possibilities, and that there are no other uses of your money that you wish to consider. Finally, suppose it is possible to buy some information concerning your problem. A business expert of your acquaintence has heard of two other business ventures of the type you're interested in; for a $100 fee he would research the problem for you to find out how many of the two were successful. This problem can be diagrammed in the form of a decision tree, as shown in Figure 3. Note that the decision tree lays out, in chronological order, all possible decisions and uncertain events; by convention, the decision points are represented by squares and the uncertain events by circles. If you invest in the bank, then the decision tree shows a sure return of $1060 (the original $1000 plus the 6% interest) at the end of the year. Similarly if you invest in the business you will have either $2000 or nothing at the end of the year. If you purchase the information, then you will find out that none, one, or two of the other ventures were successful. This is treated as an uncertain event since you don't know in advance which of these is the true case. After receiving this information you can decide on the bank or the business investment, with the possibilities of gain or loss as shown. Note that the $100 cost of the information has been taken into account in calculating the payoffs.

Even for this simple problem the decision tree is an extremely useful device for organizing one's thinking, for decomposing a large problem into a series of smaller ones, and for gathering information. A decision tree also serves as a good communication tool in outlining a problem to

Figure 3. Decision Tree



someone else. Decision trees have the advantage of being easy to draw and manipulate, making them useful even when high-powered analysis is not warranted.

C.2. Determining Uncertainty

A critical factor in the investment problem outlined above is the probability of the business being successful. One rarely knows in advance, of course, what the odds are, but usually there is at least a vague impression of some kind (the business "looks promising" or perhaps "seems risky"). It is possible to quantify these impressions by interviewing the decision maker, or better yet, an expert in the field, to determine a probability distribution of the odds. The probability distribution can then be used to determine the attractiveness of the business venture. The probability data can also be combined with objective data, such as is obtained on the "purchase information" option, to determine whether the venture still looks good after the information comes in, and to determine whether or not the information itself is worth the $100 cost.

C.3. Determining Preferences for Outcomes

In our example a single measure of effectiveness, namely the amount of money at the end of the first year, is used. Even in this case it is not clear how to proceed; for one thing, people's attitudes towards risks differ. It may well be optimal, for example, for a poor man to pass up an otherwise attractive investment because the chances of loss are too great. Even when two individuals have the same wealth one person may be more willing to take chances than the other. A method for dealing with these considerations was first suggested by von Neumann and Morganstern (<u>Theory</u>

of Games and Economic Behavior, Princeton University Press, 1944). Their idea was to pick a "best" outcome and a "worst" outcome which are at least as good and bad, respectively, as any outcome you expect to get. In the investment example, the best and worst possible outcomes are \$2000 and -\$100. Then for each possible intermediate outcome, one must assess a probability such that the intermediate outcome is exactly as attractive as a gamble between the best and worst outcomes. This probability is called the utility of the outcome. For example, consider the \$1060 which we would receive by investing in the bank. We assess the utility of \$1060 by determining a probability, which we will call p, so that the gamble in Figure 4. is neither more nor less attractive than \$1060 for sure. If p were nearly one then the gamble would be more attractive, while if p were nearly zero the \$1060 would be more attractive, indicating that there must be some value of p between zero and one where the choices are equally attractive. Note that the value of p chosen would vary from individual to individual, depending on the decision maker's personal attitudes towards risk.

Finally, von Neumann and Morganstern point out that the value of p (or the utility) is a measure of the relative attractiveness of the \$1060 consequence, and prove that the expected value of the utilities of end points is a valid decision criterion under uncertainty. To solve the investment problem, then it is necessary only to assess the utility for each end point, calculate the expected utility for each decision, which is easily done, then choose the action with the highest utility.

The validity of the utility approach depends upon certain behavioral axioms, or observations on rational behavior. Briefly, the major ones are:

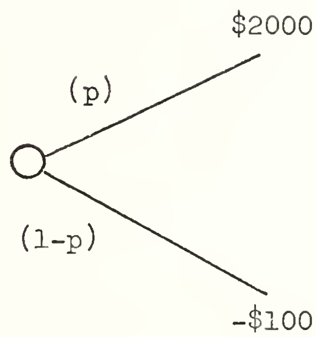
Figure 4. Utility Assessment Example

You may have either

A $1060

or

B The gamble



which gives a payoff of $2000 with probability p
and a payoff of -$100 with probability (1-p)

You must set the value of p so that A and B are equally attractive.

a) given two consequences A and B, then either A is preferred to B, B is preferred to A, or both A and B are equally attractive;

b) if A is preferred to (indifferent to) B and B is preferred to (indifferent to) consequence C, the A is preferred to (indifferent to) C;

c) given a utility assessment problem such as is outlined on Figure II.4., it is always possible to find a value p such that the gamble and the "for sure" amount are equally attractive; and

d) if consequence A is preferred to consequence B, then of two different gambles between A and B, the one offering the larger chance at A is preferred.

These seem to be reasonable assumptions, but it has been observed that people don't always act according to the axioms. This fact indicates that utility theory may not be a good <u>descriptive</u> theory, but emphasizes its potential usefulness as a <u>prescriptive</u> theory, i.e. one which indicates improved decision methods.

In the case where multiple measures of effectiveness must be used, the same basic ideas of utility theory hold. Due to practical problems, however, it is possible to assess a multidimensional utility function only if certain assumptions about one's preferences hold. Fortunately, for most problems the assumptions are valid, making it possible to use the utility approach. These issues are discussed more deeply in the Appendex.

C.4. Obtaining Results

Once the problem has been structured and the probabilities and preferences assessed, obtaining results is a straightforward computational matter. Simple problems can be solved by hand, while for more complex analyses a number of computer methods can be used. The hardest part, by far, in a decision analysis is in structuring the problem and gathering data, rather than in calculating the solution. A

good deal of "art" is required in selecting the portions of a problem to explicitely represent, as a decision tree can rapidly become overly complex if too much detail is included. As discussed in Section B.2.e., analysis is generally a cyclical, rather than a linear process. This comment applies particularly to this type of analysis. The first cut at a problem should outline major alternatives and outcomes only roughly. After lopping off the least promising branches of the initial tree, the remaining part can be elaborated, and this process continued as long as is necessary.

D. Use of Formal Decision Theory in Organizations

In this section the question of applicability of the decision analytic techniques outlined above is taken up once again. In Section A. some questions were raised concerning the role of formal analysis in real organizations, indicating that it is important to identify the types of problems for which formal techniques would be useful. One way of approaching this issue is to summarize successful applications of the method. This is done in Section D.1. Then in Section D.2. some conclusions regarding applicability are discussed.

D.1. Applications of Decision Analysis

Decision analysis, in its present form, resulted from a marriage between a particular school of thought concerning statistical analysis (the so-called "Bayesian" approach) and the von Neumann - Morganstern theory of utilities. Von Neumann and Morganstern were interested primarily in applications in economics, giving that side of the union a strongly business oriented bent, and as the union was

consummated largely in graduate schools of business, most of the applications work has been in a business setting. Reinforcing this propensity has been the fact that business problems have a natural, easily measured, common measure of effectiveness, namely profit.

D.1.a. Business Applications

An important early application of decision theory is Markowitz (1959). Markowitz was concerned with the rational investment of funds in a portfolio of potential investments, each characterized by an expected monitary return and a degree of riskiness. The portfolio problem is how to determine the investment, or mix of investments, which optimizes the return/risk tradeoff. This line of work has been considerably expanded in recent years; the portfolio selection literature is too large and diverse to review here, but a good deal of it utilizes decision analysis methodology.

The portfolio selection process has a direct analogue in business decisions involving capital investment. Matheson (1969) discusses an analysis of new product development alternatives. Briefly, a major manufacturing research company has developed two compounds for a particular market, and the decision must be made to do final development on neither, both, or only one of them, and if the latter, to decide which one. Matheson presents a discussion of the analytic process, the results and presents his recommendations. The analysis showed that one of the two products was definitely more promising than the other, but that even the better of the two products did not look profitable. However, this result was highly sensitive to the assumed size of the international market. As a result, the company undertook a more extensive analysis of the

international market. Cook (1968) presents another analysis of a product development, this time in the atomic power field. Four different product development alternatives for atomic electric generating stations were analyzed. A complex computer model of the market, costs, demands, and sales aspects of the problem was constructed and evaluated by decision analytic techniques. Cook summarized the value of the analysis as follows:

1) The deterministic, sensitivity, and uncertainty evaluations can be modeled in sufficient detail to demonstrate intuitively satisfying characteristics and magnitudes.

2) Some of the investigations, particularly venture timing, the effect of margins, and the time value of money, produced information that would not have been available either quantitatively or intuitively otherwise.

3) Sensitivity analysis is a powerful tool in evaluating the parameters that are of greatest influence, in establishing an understanding of single and multiple responses, and in establishing on a well-justified basis an approach to economic modeling.

4) The uncertainty analysis developed methods of prior building that enabled the communication of a great deal of information about the system which had, heretofore, been undeveloped. The method of simulation can be used on complex systems with reasonable cost. A great deal was learned about the technical - economic system uncertainties by the thinking required to develop the basis for uncertainty analysis. Risk can thus be examined both on the basis of the expected outcomes and also upon the distribution functions of uncertainty.

5) Outstanding advantages in thinking about alternatives, updating information, and considering new situations that present themselves are available using these techniques. The models developed allow such

steps to be done easily and quickly, and the thinking upon which each step is based is documented so that communications of ideas can be made without introducing vagaries. [Cook(1968), pp. 353-354].

Additional analyses of a similar nature are described in Frederick (1973) and Laessig & Silverman (1974). Frederick describes a product pricing problem for butadiene, a petrochemical product, in which multiple decsion criteria were considered. The article by Huber (1974) contains a review of a number of field studies, primarily business oriented, in which multidimensional utility models were used. Laessig & Silverman discuss a risk analysis technique for use in capital project evaluation. A more complete and general discussion of risk analysis in capital projects is contained in Spetzler (1968). Spetzler interviewed a number of executives of a company, then used the resultant utility assessments to formulate a corporate risk policy. The risk policy has been used for a number of major projects within the company. It was (at the time of writing) too early to see concrete results, but the educational process attendant to formulating the risk policy was itself seen as a significant benefit.

Decision analysis has also been shown to be useful in settings other than investment problems. Keeney (1969) discusses an application of multidimensional utility theory to determine the optimal organization of a telephone network. The object was to maximize the degree of service, as determined by the percentage of the time lines are availiabe to two different customer groups.

Perhaps the best summary of this section is found in Brown (1970). In this article the results of a survey among firms using, or who have used, decision analysis, are reported. The firms surveyed included organizations with

several years of active experience in decision analysis, some where the method is fairly new but is in active use, some where there is interest but little application, one or two where decision analysis has been a disappointment, and two consulting firms with expertise in the area. Brown found that general decision-making procedures aren't radically affected by the presence of decision analysis, but that individual decisions are often profoundly affected to the good. The consensus among the survey participants was that the methods had enormous potential which is not yet realized. Major problems seen in using the method are: 1) management education; 2) communications between the analysts and the managers for whom the analysis is done; 3) in many organizations it is difficult to identify who is responsible for specific decisions; and 4) organizational obstacles. Brown concludes that "If there is one dominant feature that distinguishes the successful from the less successful applications of (decision analysis), judging from the findings of this survey, it is the organizational arrangements . . . The most successful appears to be the 'vest pocket' approach, where the analyst works intimately with the executive and typically reports to him."

D.1.b. Medical Applications

A rich literature has grown up describing applications of decision theory to medical problems. Among the reasons for this are: medical decisions have important consequences in cost, suffering, and death; medical problems are complex and involve uncertainty; the volume and fragmentation of knowledge requires an effective integrating structure; data is widely available and relatively easily obtainable; and public interest in medicine is high. Although medical decisions per se are not of interest in this research, the methodology of applying decision analysis which is

demonstrated in this field is. In particular, medical decisions typically require consideration of multiple objective criteria, and a number of techniques for dealing with this problem are described in this literature.

A number of articles describe the application of decision theory to specific medical diagnostic or treatment problems. Giauque and Peebles (1974) discuss analysis of the treatment of strep throat and rheumatic fever, developing in the process a scheme for evaluating consequences with as many as ten attributes. Ginsberg (1971) performs a similar analysis for the pleural - effusion syndrome (which involves fluid in the lung cavity), while Ginsberg and Offensend (1968) discuss a diagnostic problem in spinal bone disease. The approach to the multidimensional consequence evaluation in both these cases was somewhat simpler. Thomas et. al. (1973) analyze the diagnosis of heart disease, while Schwartz et. al. (1973) discuss hypertension (high blood pressure). Some of the papers [particularly Giauque and Peebles (1974), Ginsberg (1971), and Schwartz et. al. (1973)] contain general discussions of decision analysis in addition to the specific studies.

More general approaches to broad problems are contained in Giauque (not yet published) and Lustid (1971). Giauque discusses a utility approach to measuring the quality of health care, with a particular application in the treatment of hypertension. Lusted discusses the use of decision theory in interpreting X-rays. Lusted (1968) contains an extensive bibliography of other medical analyses.

D.1.c. Public Sector Applications

Public sector applications are particularly difficult

to analyze since they have neither the natural measurement criterion of profit found in business applications nor the data availability of medical applications. Decision analysis offer methods both for dealing with the multiple criteria required in public sector analysis and the uncertainties caused by lack of data, leading to a significant literature on public sector applications.

Some of the studies concentrate on relatively independent problems with well defined decisions. Howard, Matheson, and North (1972), for example, discuss the problem of deciding whether or not to seed hurricanes with silver iodide. Experiments with seeding have shown promising results, but a decision to seed a hurricane bearing down on populated areas carries legal and moral consequences. Howard et. al. used decision analysis to examine the problem and to explore other decision alternatives besides the "seed" and "don't seed" alternatives. In Giauque (not yet published - II) a scheme to determine an optimal method of oil spill cleanup in harbors, depending on the geographic and climatic conditions at the harbor, is presented. Keeney (1969) explores blood bank inventory control and cost / benefit relationships of depth surveying in the Cape Cod Ship Canal through use of a multidimensional utility analysis.

A second group of papers are broader in scope, but still deal with well defined problems and priorities. Gear (1974) and Roche (1972) present analysies of planning in education. Gear, after discussing approaches to a number of common educational decision problems, presents an analysis of secondary school pupil allocations between adjacent geographical areas. Roche discusses an extensive investigation into the problem of resource allocation among different subject areas in a secondary school. This involved determining the tradeoffs the school board and

school administration are willing to make among proficiency levels in the various subjects. Other applications areas include space and military planning. Matheson (1969) presents a method for planning payloads on unmanned Martian exploration vehicles. Power (1973) discusses an interactive system, utilizing decision analytic concepts, to plan cost and schedule estimates for antiballistic missile programs.

Finally, some studies work with very large problems directly affecting large segments of the population, where alternatives and goals are imperfectly understood and poorly articulated. Stanford Research Institute (1968) conducted a study for the Mexican Government, in which a strategy for electrical power system expansion for the entire country over the next 30 years was derived. This involved forecasting a complex array of power needs, technical advancements, price movements of various fuels, and so forth, over this time frame. In addition, a number of social trade-offs had to be considered. For example, the impact on employment, self-sufficiency, side benefits, and technical expertise required are very different for say, nuclear versus hydroelectric generating plants. This study is referred to and discussed in Matheson (1969) and Howard (1971).

In a separate study, Keeney and Nair (1974) discuss the complex issues and tradeoffs involved in licensing nuclear power plants within the United States, and propose a decision analytic based approach to solving these issues. Hammond (1971) and Ellis & Keeney (1972) derive methods to analyze problems of strategic military planning and air pollution control, respectively. Finally, deNeufville and Keeney (1972) consider the possibilities for future development of the Mexico City, Mexico airport. Two possible locations are considered, and a number of possible development strategies discussed. A number of effectiveness

measures were used, specifically noise problems, cost, capacity, safety, transportation time, and the number of people displaced by the airport expansion.

D.2. Applicability of Decision Analysis

The summary above, although by no means exhaustive, is extensive enough to show the variety of problems for which and contexts in which decision analysis has demonstrated usefulness. Problems can be simple or complex, single or multi attributed, well defined or nebulous, big or small. Decison contexts can be business, medical, educational, defense, public, private, simple, or complex. Is it possible to glean, then, any general principles of successful application from this survey?

The overriding impression one gets from reading the applications literature is the importance of the relationship between the analyst and the decision maker. What is studied does not seem to be nearly as critical as how the study is performed. In the words of Keeney and Raiffa (1972), "The metadecision of whether or not to do formal analysis cannot be divorced from the questions of organizational structure, of the personal incentives for the people involved, and of the quality of the analysts." Brown (1970) also emphasizes the quality of the analyst - client relationship. In a way, this is disappointing, since the above amounts to saying "Get a good analyst and a motivated manager, get them working well together, and no matter what the problem is you'll get a good analysis." This is the same thing that operations researchers have been saying for years, and like it or not, it seems to be true in decision analysis as well.

Some additional light on this issue can be obtained by

referencing Figure 1. (A Decision Taxonomy) on page 14 of this report. Branches of the taxonomy tree marked with an asterisk are those where decision analysis is most likely to be useful. If problems are well defined, certain, and have a single decision criterion (measure of effectiveness), the particular strengths of decision analysis aren't really called into play. In other types of problems, though, the usefulness of the method can be dramatic, either alone or in conjunction with other techniques. The structural aspects of decision analysis are helpful in defining problems, specifying the magnitude of uncertainty, providing for contingent decisions, and determining the sensitivity of results to assessments and assumptions. The utility formulation allows one to specify objective criteria valid under risk, and to reduce multiple criteria to a single criterion.

Bibliography

1. Brown, R.V.: "Do Managers Find Decision Theory Useful?", Harvard Business Review, May - June 1970

2. Cook, W.H. "Decision Analysis for Product Development," IEEE Transactions in System Science and Cybernetics, Vol. SSC-4, No. 3, Sept. 1968

3. DeNeufvill, R., and Keeney, R.L.: "Use of Decision Analysis in Airport Development for Mexico City," in Drake et. al., Analysis of Public Systems, The MIT Press, Cambridge, Mass., 1972

4. Ellis, H.M., and Keeney, R.L.: "A Rational Approach for Governemnt Decisions Concerning Air Pollution," in Drake et. al., Analysis of Public Systems, The MIT Press, Cambridge, Mass., 1972

5. Frederick, D.G.: "Multiple Objectives in Baysian Analysis: An Applied Case," in Cochrane & Zeleny (ed.), Multiple Criteria Decision Making, University of South Carolina Press, Columbia, So. Carolina, 1973

6. Giauque, W.C. and Peebles, T.C.: "Application of Decision Theory in Determining Optimal Test-Treatment Strategies for Streptococcal Sore Throat and Rheumatic Fever", Technical Report, Naval Postgraduate School, Monterey, Calif., 93940

7. Giauque, W.C.: "A Utility Approach to Quality of Care Measurement," Naval Postgraduate School, Monterey, Calif., 93940 (not yet published)

8. Giauque, W.C.: "Examination of Alternative Methods of

Employing Oil Control Booms," Naval Postgraduate School, Monterey, Calif., 93940 (not yet published-II)

9. Gear, A.E.: "Applications of Decision Trees to Educational Planning," Presented at the Joint National Meeting, ORSA/TIMS, Boston, Mass. April 1974

10. Ginsberg, A.S. and Offensend, F.L.: "An Application of Decision Theory to a Medical Diagnosis - Treatment Problem," IEEE Transactions in System Science and Cybernetics, Vol. SSC-4, No. 3, Sept. 1968

11. Ginsberg, A.S.: Decision Analysis in Clinical Patient Management With an Application to the Pleural - Effusion Syndrome, RAND, R-751-RC/NLM, 1971

12. Hammond, J.S.: Defensive Decisionmaking: Prudent Versus Excessive Conservatism, RAND, R-715-PR, June 1971

13. Howard, R.A.: "Decision Analysis in Systems Engineering," Presented at the "Systems Concepts for the Private and Public Sectors" Seminar Series at the California Institute of Technology, April 13, 1971

14. Howard, R.A., Matheson, J.E., North, D.W.: "The Decision to Seed Hurricanes," Science, Vol. 176, 16 June 1972

15. Huber, G.P.: "Multi-Attribute Utility Models: A Review of Field and Field-Like Studies," Management Science, Vol. 20, No. 10, June 1974

16. Keeney, R.L.: Multidimensional Utility Functions: Theory, Assessment and Applications, Technical Report No. 43, Operations Research Center, MIT, Oct. 1969

17. Keeney, R.L., and Raiffa, H.: "A Critique of Formal Analysis in Public Decision Making" in Drake et. al., Analysis of Public Systems, The MIT Press, Cambridge, Mass., 1972

18. Keeney, R.L., and Nair, K.: Decision Analysis for Siting of Nuclear Power Plants - The Relevance of Multiattribute Utility Theory, Technical Report No. 96, Operations Research Center, MIT, June 1974

19. Laessig, R.E. and Silverman, S.W.: "Capital Project Planning Using a Monte Carlo Based Risk Analysis Computer Model," Presented at the Joint National Meeting, ORSA/TIMS, Boston, Mass. April 1974

20. Lusted, L.B.: Introduction to Medical Decision Making, Illinois, Charles C. Thomas, 1968

21. Lusted, L.B.: "Decision - Making Studies in Patient Management," New England Journal of Medicine, Vol. 284:416-424 (Feb. 25), 1971

22. Markowitz, H.M.: Portfolio Selection, John Wiley & Sons, Inc., New York, 1959

23. Matheson, J.E.: "Decision Analysis Practice: Examples and Insights," Stanford Research Institute, Menlo Park, Calif. 94125; Presented at the Fifth International Conference on Operational Research, Venice, 1969

24. Power, C.S.: "Cost - Measurement and Analysis," presented at the 32nd meeting of the Military Operations Research Society, 1973

25. Roche, J.: Unpublished Doctoral Thesis, Harvard

Graduate School of Business Administration, 1972

26. Rubel, R.A.: Decision Analysis and Medical Diagnosis and Treatment, Unpublished Doctoral Thesis, Harvard University, Graduate School of Business Administration, 1967

27. Schwartz, W.B., Gorry, G.A., Kassirer, J.P., and Essig, A.: "Decision Analysis and Clinical Judgement," The American Journal of Medicine, Vol. 55, Oct. 1973

28. Spetzler, C.S.: "The Development of a Corporate Risk Policy for Capital Investment Decsiions," IEEE Transactions in System Science and Cybernetics, Vol. SSC-4, No. 3, Sept. 1968

29. Stanford Research Institute, Decision Analysis Group, "Decision Analysis of Nuclear Plants in Electrical System Expansion," prepared for Comision Federal de Electricidad, Mexico City, SRI Project 6496, December 1968

30. Thomas, M.U., Condos, W.R. Jr., and Knox, E.W.: "A Decision Analytic Approach to the Diagnosis of Coronary Heart Disease," presented at the 1973 IEEE Conference in Systems, Man and Cybernetics, Boston, Mass.

Appendix - Decision Analysis Methodology
(based on a Masters Thesis by Kenneth H. Kerns, LCDR, USN)

Man is often confronted with situations in which the consequences of any action he takes are not certain. Events may intervene which he can not control or predict with certainty. A large number of decisions under uncertainty are made by intuition. The intuitive decision process is accomplished in the decision-maker's mind. Because of this, there is no way to verify that this type of decision is the logical consequence of the choices, information and preferences that were available to the decision-maker. For many problems, however, it is important that the decision-maker is able to show people why he arrived at a particular decision and also for them to be able to see what changes in factors surrounding that decision might have led to a different decision. Another characteristic of the intuitive decision process is the human tendency to equate the quality of the decision with the quality of the outcome it produces. For example, consider a situation where an investor decides to buy some new stock. If he loses money, the tendency is to say that the investor made a bad decision; conversely, if he makes money, then he made a good decision. A good decision is a decision which maximizes the probability of a good outcome; hence, making a good decision is no guarantee of a good outcome. The decision-maker has control of the decision. He does not have control of the outcome.

The purpose of decision analysis is to allow the decision-maker to make consistent good decisions and to

formulate them in quantitative terms that can be conveyed from one person to another. Formal decision analysis is a systematic process comprising the following steps:

(1) structuring the problem,
(2) assessing relative preferences for possible consequences,
(3) evaluating the probabilities for uncertainties and
(4) determining the best course of action from the information in the preceeding steps.

This process is an iterative process. First, a broad description of the problem with rough assessments of the preferences for the consequences and probabilities for the uncertainties is analyzed. On the basis of the first analysis, alternatives are added or removed from consideration. The measurements are refined and the process is repeated until there is satisfaction with the results of the analysis.

The purpose of this appendix is to acquaint those unfamiliar with decision analysis with its theory and techniques. This appendix is organized to explain the methodology of decision analysis for each step in the formal analysis. Before proceeding, it is necessary to explain certain terms and notations which are used throughout the remaining parts of this thesis.

A. CLARIFICATION OF TERMS AND NOTATIONS

The terms "is indifferent to", "is preferred to", "lottery" and "utility function", are widely used in the following sections of this thesis. For clarity, they need to be explained. The term "is indifferent to" is to be used to mean the same as the statement "the decision-maker is indifferent to receiving either

of the outcomes." The term "A is preferred to B" is to be used to mean the same as the statement "the decision-maker prefers A over B."

The term "lottery" is defined as a gamble of some uncertain event E where the prize X^* is won if the event E occurs and the prize X_* is won if the event E does not occur. Let p^* represent the probability that E occurs and let $1 - p^*$ represent the probability that E does not occur. Notationally, the lottery L_E will be represented as $\langle X^*, p^*, X_* \rangle$.

The term "utility function" is defined as a function u which assigns a real value to every consequence a and b such that u(a) is larger than u(b) if and only if a is preferred to b. The notation u(a) is expressed as the "utility of consequence a" and is represented by a real number.

With the above terms clarified, the steps in a formal decision analysis process can be explained. The first step in this process is structuring of the problem.

B. PROBLEM STRUCTURE

In structuring a problem in which events are uncertain, the options or alternatives are enumerated. Next, all the events that can possibly occur are specified. As a last step, the alternatives and uncertain events are

arranged in chronological order.

A type of diagram known as a decision-flow diagram or "tree" is a useful tool in decision analysis. It is a chronological arrangement of the alternatives which are controlled by the decision-maker and the events determined by chance. To illustrate the construction of a decision-flow diagram, consider the following problem. A decision-maker is faced with two alternatives, I and II. Both alternatives involve a situation where the outcomes a or b are uncertain. If a occurs, then the decision-maker must decide between alternatives III and IV. Alternative III also involves an uncertain situation leading to either the outcome c or d.

The decision-flow diagram is shown in Figure A.1. Observe that the branching points or forks are of two types: decision forks and chance forks. A decision fork is designated by a small square and a chance fork by a small circle. There is additional information provided in the diagram which will be discussed in the sections below.

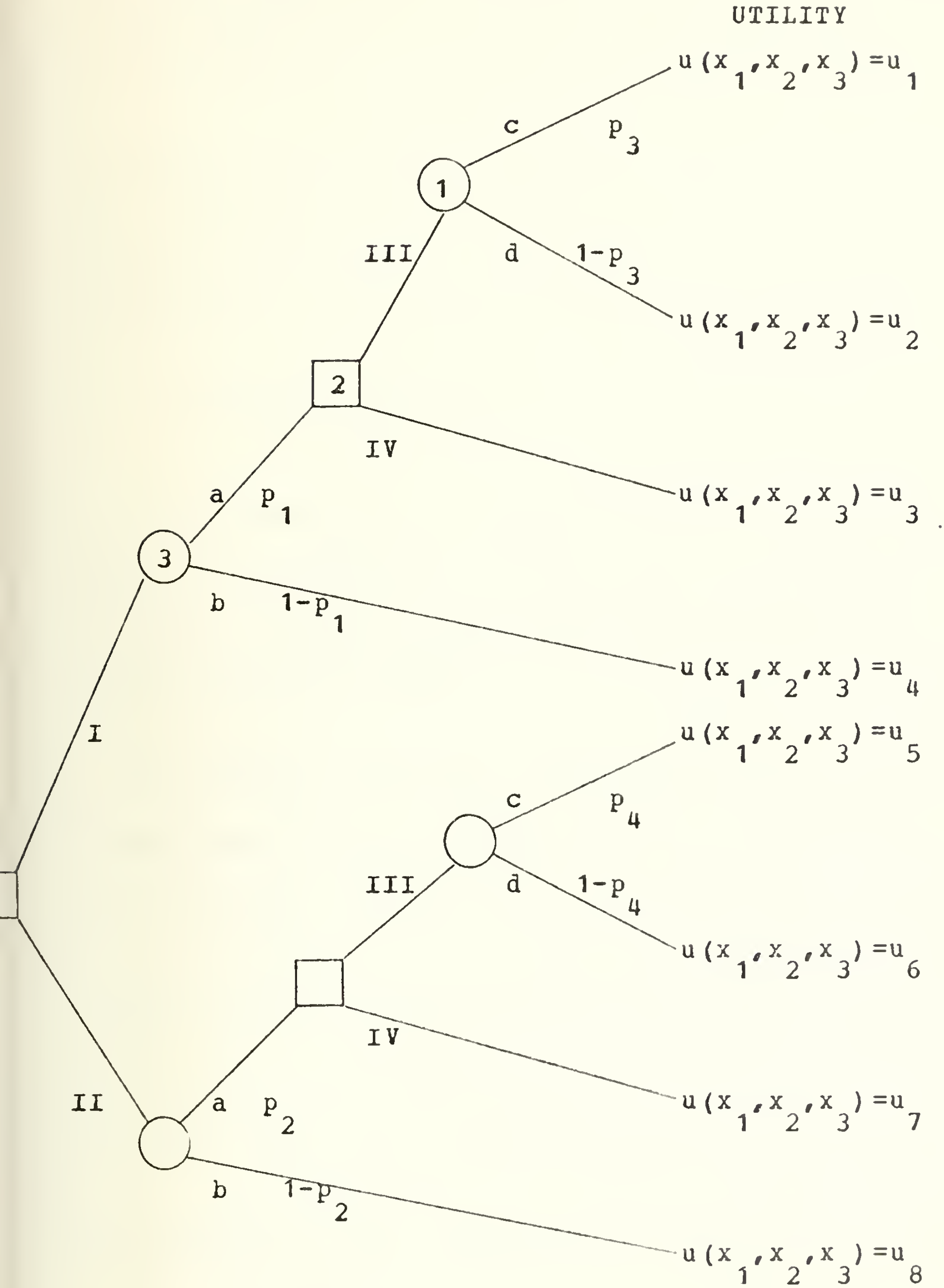
With the alternatives and uncertain events described by a decision-flow diagram, the next step in the decision analysis process is the assessment of the relative preferences for the consequences.

C. ESTABLISHMENT OF PREFERENCES

The establishment of preferences for the consequences provides the decision-maker with the basis for the rational choice between the alternatives. This depends upon the views and attitudes of the decision-maker.

The consequences may encompass a number of factors or attributes such as cost, schedule and performance. These attributes might also be of an intangible nature such as goodwill, morale and politics.

EXAMPLE DECISION-FLOW DIAGRAM



: DECISION FORK

: CHANCE FORK

FIGURE A.1.

In this step in the decision analysis process, an objective function is defined to indicate a measure for the preferences for the consequences.

A general methodology for defining an objective function in decision analysis problems exists in the form of utility theory. Consequences may be described by a single attribute or a multiple set of attributes. Both situations are presented below.

1. Single Attributes

In the case of a single attribute, an objective function, hereafter called a utility function, can be defined which has the property that the maximum expected utility among the alternatives indicates the most preferred action.

A utility function with a single attribute can be constructed in the following manner. Define X^* and X_* as the upper and lower limits over a range of possible consequences X_i such that $X^* \geq X_i \geq X_*$. For every possible consequence X_i, define the utility $u(X_i)$ as the value p_i such that the decision-maker is indifferent to receiving X_i for certain and receiving the lottery $\langle X^*, p_i, X_* \rangle$. The value of p_i ranges from zero to one, where by convention, $u(X^*)$ equals one and $u(X_*)$ equals

zero [Ref. 12].

Once a set of points (X_i, p_i) have been established, a utility curve may be drawn. Figure A.2. illustrates three possible utility curves. A utility curve generally has two characteristics. It is smooth and the general shape of the curve is either convex, straight or concave as illustrated respectively by curves 1, 2 and 3 of Figure A.2. Any break in the curve would indicate either an inconsistency in the choices for p_i in the lottery $\langle X^*, p_i, X_* \rangle$ used to assess the points of the curve, or a quantum jump in preference for a small change in X_i. A convex curve indicates a risk averse behavior. That is, the decision-maker is more inclined to take a consequence known for sure than to take a gamble with the same expected value. A concave curve indicates that the decision-maker is risk seeking. He is more inclined to take the gamble than to take the known consequence. A straight line indicates that the decision-maker acts on the expected value of the consequence. He is neither risk averse nor risk seeking.

Once the utility curve is established for a single attribute consequence, a value from one to zero is assigned to each consequence corresponding to the point on the curve. A higher value for a consequence indicates greater preference for that consequence than for a consequence with a lower utility value.

EXAMPLES OF UTILITY CURVES

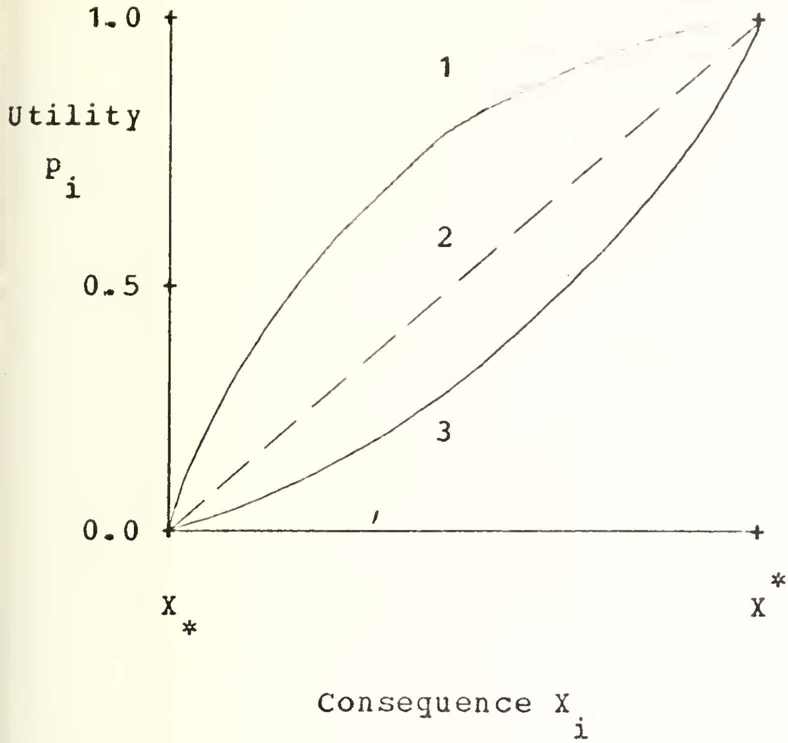


FIGURE A.2.

2. Multiple Attributes

The basic concept of the construction of a utility function with a single attribute described above can be generalized to the case where many attributes must be considered. However, the above assessment scheme is impractical. First, too many points must be assessed. Secondly, humans find it difficult to think in terms of multiple attributes. In decision problems under uncertainty, many people when faced with situations where more than one attribute is relevant, tend to pick the one attribute judged most important to them and then make the decision on that factor alone.

There are procedures for decomposing a multiple attributed utility function into combinations of unidimensional functions. Conditions required for decomposition include the properties of utility independence, pairwise preferential independence and pairwise marginality. These are described below.

Keeney [Ref. 1] shows that a multiattributed utility function can be expressed in one of two forms, additive or multiplicative, dependent on which of the properties of utility independence, pairwise preferential independence or pairwise marginality hold. If a utility function of multiple attributes can be expressed in these forms, then the task of defining the utility function is much easier. Suppose $\underline{X}$ = $(x_1,...,x_n)$ describes a consequence where $u(\underline{X})$ denotes the utility of the consequence $\underline{X}$. Utility independence is defined in the following manner. Let $x_{\bar{i}}$ =

$(x_1,\ldots,x_{i-1},x_{i+1},\ldots,x_n)$. The attribute x_i is utility independent of $x_{\bar{i}}$ if the decision-maker's relative preference for x_i, with $x_{\bar{i}}$ held fixed, is the same regardless of the actual value of $x_{\bar{i}}$ chosen. Order one mutual utility independence is defined to mean that x_i is utility independent of $x_{\bar{i}}$ for all i. If order one mutual utility independence holds then $u(\underline{X})$ can be expressed in the quasi-additive form

$$u(x_1,\ldots,x_n) = \sum_{i=1}^{n} u_i(x_i) + \sum_{i=1}^{n}\sum_{j=1}^{n} c_{ij}\, u_i(x_i)\, u_j(x_j) + \ldots.$$

Pairwise preferential independence is said to hold if the trade-offs one is willing to make between attributes taken two at a time, are not dependent on the values of the remaining attributes. Let $X_{\bar{ij}} = (x_1,\ldots,x_{i-1},x_{i+1},\ldots,x_{j-1},x_{j+1},\ldots,x_n)$, and let $x_{\bar{ij}}$ be a particular value from $X_{\bar{ij}}$. The attributes x_i, x_j are pairwise preferentially independent of $X_{\bar{ij}}$ if one's preference order for the consequences $(x_i, x_j, x_{\bar{ij}})$ with $x_{\bar{ij}}$ held fixed, does not depend on the particular value $x_{\bar{ij}}$ [Ref. 1].

If for any pair of attributes x_i and x_j, the lottery $\langle (x_i,x_j),0.5,(x_i^0,x_j^0)\rangle$ is indifferent to the lottery $\langle (x_i,x_j^0),0.5,(x_i^0,x_j)\rangle$ then pairwise marginality is

said to hold [Ref. 2].

With the ideas of utility independence and pairwise preferential independence presented, Keeney's results can be more precisely stated [Ref. 1]. Let $\underline{X} = (x_1, \ldots, x_n)$ be as previously defined, with $n \geq 3$. If, for some x_i, x_i and x_j are pairwise preferentially independent of $(x_1, \ldots, x_{i-1}, x_{i+1}, \ldots, x_{j-1}, x_{j+1}, \ldots, x_n)$ for all $j \neq i$ and x_i is utility independent of $x_{\bar{i}}$, then either

$$u(\underline{X}) = \sum_{i=1}^{n} k_i \, u_i(x_i) \tag{1}$$

or

$$1 + K\,u(\underline{X}) = \prod_{i=1}^{n} [1 + Kk_i u_i(x_i)] \tag{2}$$

where u and u_i are utility functions scaled from zero to one, the k_i are scaling constants with $0 < k_i < 1$ and $K > -1$ is a non-zero scaling constant. Equation (1) is the additive form and equation (2) is the multiplicative form.

Given that the conditions of Keeney's Theorem hold, he provides a property required to show whether the function is additive (1) or multiplicative (2). He shows that if pairwise marginality holds then the function must be additive; otherwise, it is multiplicative. Table I summarizes the properties necessary for each simplification [Ref. 2].

TABLE I

UTILITY FUNCTION SIMPLIFICATION

implification	Properties		
	1st order utility indep.	Pairwise preferential indep.	Pairwise marginality
uasiadditive form	X		
ultiplicative form	X	X	
dditive form	X	X	X

Referring to Figure A.1., there are three attributes x_1, x_2 and x_3 which describe each outcome of the tree. For illustration, the following utility function might be used :

$$u(x_1,x_2,x_3) = u(x_1) + u(x_2) + u(x_3) = u_i.$$

This utility function, in the additive form, maps the consequences x_1, x_2 and x_3 into a scalar value indicated by u_i, where $i = 1,\ldots,8$, at each branch-tip of the tree.

D. JUDGMENTAL PROBABILITIES

The decision-flow diagram is one of the decision analysis methods used in structuring a problem. Utility functions can be used for the assignment of preferences for the consequences of the outcomes at each tip of the tree. What remains to complete the information included on the decision-flow diagram is the assignment of the judgmental probabilities at the

chance forks representing the uncertain events. This is the third step in the decision analysis process.

Raiffa [Ref. 3] addresses the question of whether the decision-maker's hunches or vague impressions should be calibrated, and if so, how this should enter into the formal decision analysis process. He argues that if a decision-maker wishes to act consistently, then he ought to assign values to judgmental probabilities such that the sum of the probabilities of an event occurring and not occurring equals one. This judgmental probability assessment for an event should not depend on the outcomes. He points out that judgmental probabilities satisfy the usual rules of probability theory and can be used in the same manner as objective probabilities.

Judgmental probabilities are used as a measure of the decision-maker's beliefs concerning the uncertainty of an event occurring, provided that these beliefs are consistently applied to every uncertain event in the analysis. They are assigned to each chance fork of the tree. In Figure A.1., they are represented as p_1, $1-p_1$, p_2, $1-p_2$, p_3, $1-p_3$, p_4 and $1-p_4$. With this information, the final step in any iteration of the decision analysis process is to determine the recommended course of action.

E. RECOMMENDED COURSE OF ACTION

Determination of the recommended course of action involves a sequence of calculations called by Raiffa [Ref. 3] the "averaging out and folding back"

procedure. This procedure is often referred to as the process of backwards induction in the theory of dynamic programming [Ref. 3]. The procedure starts at the tips of the tree and consists of computing the expected utility of each chance fork and the selection of the greatest utility at each decision fork. The process is repeated for each level of the tree until the starting decision fork is reached. The alternative with the greatest expected utility is selected as the recommended course of action. The selection of the maximum expected utility is an appropriate means of determining actions consistent with the decision-maker's attitudes and opinions [Ref. 2]. This point is presented and developed in such sources as Schlaifer [Ref. 4] and Pratt, Raiffa and Schlaifer [Ref. 5].

To illustrate the "averaging out and folding back" process, the information contained in Figure A.1. is used. Starting at the chance fork labeled 1, the expected utility is computed as

$$u_1 p_3 + u_2 (1-p_3) = E_1$$

Moving backwards in the tree, the next fork encountered is a decision fork, labeled 2. The value of E_1 or u_3, whichever is greater, is selected. For illustration, E_1 is selected. Continuing backwards through the tree, a chance fork, labeled 3, is encountered. At this point, the expected utility of the chance fork is computed as

$$E_1 p_1 + u_4 (1-p_1) = E_2.$$

Alternative I has now been reached and the expected utility of this alternative is E_2. In similar fashion, the expected utility of alternative II is computed. The results are compared and the alternative with the greatest expected utility is selected as the recommended course of action.

F. SUMMARY

On most occasions, people make decisions intuitively and more or less inconsistently. There are occasions when the decision must be made in a reasoned, deliberate manner. Decision analysis methodology was introduced to provide this. In the systematic process of decision analysis, the decision-maker starts by structuring the anatomy of his problem in a decision-flow diagram that depicts the chronological interactions between his alternatives at any stage and the events which are controlled by uncertainty. He scales his preferences for the consequences at the tips of the decision tree in terms of utility values and scales his judgments about uncertain events in terms of probability assignments at the chance forks in a consistent manner. Finally, he selects his best strategy for action by the process of "averaging out and folding back."

Most "real life" problems are complex. Trees exhibiting the structure of these problems can be so complex as to make a detailed analysis of the alternatives impractical. An iterative process is used. Initially, alternatives and measurements are specified in a rough manner. Frequently, some of the decision branches will turn out to be nonoptimal and can be eliminated from the tree. If the decision branch is

close to the base of the tree, a sizable portion of the tree can be eliminated. After elimination, further effort can be put into refining the description of the remainder of the tree. This iterative process is repeated until the decision can be satisfactorily made. There is an "art" to analyzing real problems as described by Raiffa [Ref. 3].

References

1. Keeney, R.L., "Multiplicative Utility Functions," Operations Research, Vol. 22, pp. 22-33, January - February 1974.

2. Giauque, W.C., Prevention and Treatment of Streptococcal Sore Throat and Rheumatic Fever - a Decision Theoretic Approach, Doctoral Thesis, Harvard Business School, Boston, Mass., 1972.

3. Raiffa, H., Decision Analysis, Addison - Wesley, 1968.

4. Schlaifer, R., Analysis of Decisions Under Uncertainty, McGraw-Hill, 1967.

5. Pratt, J.W., Raiffa, H., and Schlaifer, R., Introduction to Statistical Decision Theory, McGraw - Hill, 1965.

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